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Wide Area UXO Contamination Evaluation by Transect Magnetometer Surveys

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ACRONYMS AND ABBREVIATIONS

AFB	Air Force Base
AMTADS	Airborne Multi-Sensor Towed Array Detection System
AOI	area of interest
APG	Aberdeen Proving Ground
ARL	Army Research Laboratory
AS	Analytic Signal (nT/m)
ASR	Archives Search Report
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
COC	Certificate of Clearance
COG	course-over-ground
CSM	conceptual site model
DAS	Data Analysis System
DoD	Department of Defense
DSB	Defense Science Board
EM	electromagnetic
EMI	electromagnetic induction
EOD	explosive ordnance disposal
ESTCP	Environmental Security Technology Certification Program
FUDS	Formerly Used Defense Site
GEMTADS	MTADS GEM-3 Frequency-Domain EMI Sensor Array
GPS	Global Positioning System
LiDAR	Light Detection and Ranging
MMRP	Military Munitions Response Program
MP	man-portable
MRA	Munitions Response Area
MTADS	Multi-Sensor Towed Array Detection System
NRL	Naval Research Laboratory
nT	nanoTesla
OB/OD	open burning/open detonation
PBR	Precision Bombing Range
PI	Principal Investigator
PNNL	Pacific Northwest National Laboratory
QC	quality control

ACRONYMS AND ABBREVIATIONS (continued)

RTK	real-time kinematic
SERDP	Strategic Environmental Research and Development Program
SNL	Sandia National Laboratories
SNR	signal-to-noise ratio
USACE	United States Army Corps of Engineers
UXO	unexploded ordnance
WAA	Wide Area Assessment
WAAS	Wide Area Augmentation System

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Mark Howard of NAEVA Geophysics, Inc., joined the team for the vehicular survey at the Victorville, California, site. Ben Dameron, John Adamson, and Frank Amorosanna of NAEVA assisted Nova Research with the man-portable electromagnetic (EM) survey conducted at the Victorville site.

For the Former Camp Beale demonstration, Tom Bell and Tom Furuya of SAIC also assisted the PI with project management and data processing support. Ben Dameron and Daniel Hennessy of NAEVA conducted the vehicular operations. Brian Neely, Robert Curren, James Hancock, and Li Xiaozhuang of NAEVA made up the man-portable field team. Jay Johnson of EOTI, Inc. assisted Glenn Harbaugh as Site Safety Officer and in providing explosive ordnance disposal (EOD) escort for the field teams. Randall Stringer and Christopher Sheehy of AeroTek, Inc. provided environmental escort to the field teams.

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1.0 EXECUTIVE SUMMARY

1.1 BACKGROUND

The location and cleanup of buried unexploded ordnance (UXO) has been identified as a high priority, mission-related environmental requirement of the Department of Defense (DoD). The Defense Science Board (DSB) Task Force on UXO [1] recently estimated that there are 1,400 sites suspected of containing UXO contamination covering approximately 10 million acres in the continental United States. By some estimates, as much as 80% of this acreage is quite likely not contaminated with UXO at all. Technologies that can accurately and rapidly delineate the areas within each site that are contaminated from those that are not contaminated would lead to an immediate payback in terms of reducing the acreage that must be carefully examined and potentially cleaned.

The prototypical Wide Area Assessment (WAA) site is a large area (10,000s of acres) that may contain isolated areas of concentrated UXO, such as aiming points. The Environmental Security Technology Certification Program (ESTCP) WAA Pilot Project fields a layered suite of technologies to evaluate potential WAA strategies. The top layer consists of (relatively) high-flying sensors (and aircraft) (orthorectified photography and Light Detection and Ranging [LiDAR]), designed to detect “munitions-related features” such as target rings and craters. The next layer is a helicopter-borne magnetometer array designed to detect subsurface ferrous metal directly. The magnetometer data can be used to locate and define boundaries for targets, aim points, and open burning/open detonation (OB/OD) sites. The final layer is a survey of portions of the site using ground-based sensor arrays. In conjunction with statistical transect planning, the ground survey aids in defining target locations and boundaries. We have demonstrated several such final-layer systems using ground-based a) towed-array magnetometer system, b) towed-array electromagnetic (EM) system, and c) man-portable (MP) EM systems.

1.2 OBJECTIVE OF THE DEMONSTRATION

We have demonstrated a suite of data collection and analysis methodologies to support the rapid delineation of UXO contamination within a suspect site. Transect plans were developed by Pacific Northwest National Laboratory (PNNL) and Sandia National Laboratories (SNL) in cooperation with the ESTCP Program Office. The transect plans were based on available archive information and designed to allow the efficient sampling of the demonstration sites for areas of interest (AOI) while maintaining a statistically defensible probability of traversing the types of AOIs within the site that match the criteria developed from the available archive data and collected in the conceptual site models (CSM). These transect plans were implemented and data were collected at each demonstration site. Anomaly location and a measure of anomaly magnitude were extracted from these data using an automated anomaly detection methodology. This information was provided to PNNL/SNL for analysis to rapidly delineate AOIs. With this rapid pace, it was possible to interactively plan and execute additional transects to further resolve potential AOIs while the survey team was still deployed in the field.

Total coverage surveys were also conducted in small areas (1-90 acres per area) to better characterize the overall site and to support later validation efforts. The goals of the total coverage surveys were a) to characterize background anomaly densities in areas found to be

quiet (low anomaly density) in the transect survey results, b) to characterize the falloff behavior of the anomaly density as a function of distance from known AOIs within the demonstration site, and c) to gather further information on AOIs identified either from the transect data or from other sources such as the high airborne results.

1.3 REGULATORY DRIVERS

The United States Army Corps of Engineers (USACE) is the lead agency under the Formerly Used Defense Sites (FUDS) program. USACE administers the FUDS Military Munitions Response Program (MMRP) using methods based on the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) process.

1.4 DEMONSTRATION RESULTS

As part of the ESTCP WAA Pilot Project, Nova Research, Inc., has conducted a series of vehicular and MP geophysical surveys at three of the ESTCP WAA Pilot Project demonstration sites. Data were collected at the Pueblo Precision Bombing and Pattern Gunnery Range #2 (Precision Bombing Range [PBR] #2), the Victorville PBRs Y and 15, and the Former Camp Beale, located near La Junta, Colorado; Victorville, California; and Marysville, California, respectively. Towed-array transect surveys were conducted using the Naval Research Laboratory (NRL) Multi-Sensor Towed Array Detection System (MTADS) magnetometer and EM61 MkII arrays. A MP EM adjunct was also used in areas of the Victorville and Former Camp Beale demonstration sites that were inaccessible to the towed arrays. Approximately 1-2% of each site was surveyed using transect plans developed by the ESTCP Program Office, PNNL, and SNL. Known AOIs (BT3 at Pueblo PBR #2, for example) were identified at each site, and additional AOIs were identified for further evaluation.

1.5 STAKEHOLDER/END-USER ISSUES

These demonstrations have shown that ground-based techniques can play a vital role within the WAA concept. The proximity to the UXO and the sensitivity of the sensors deployed in the ground-based systems allow for the defensible bounding of areas of UXO contamination within the overall site and provide detailed validation data for the higher altitude techniques.

2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY DEVELOPMENT AND APPLICATION

2.1.1 MTADS Tow Vehicle

The towed-array portions of the demonstration were conducted using the NRL MTADS tow vehicle. The MTADS was developed with support from the ESTCP. The MTADS hardware consists of a low-magnetic-signature vehicle that is used to tow different sensor arrays over large areas (10-25 acres/day) to detect buried UXO. The MTADS tow vehicle and magnetometer array are shown in Figure 1. Positioning is provided in real-time (5 Hz) using cm-level real-time kinematic (RTK) Global Positioning System (GPS) receivers. The positioning technology requires the availability of one or more known first-order survey control points.

Figure 1. MTADS Vehicle Towing the Magnetometer Array.

2.1.2 MTADS Magnetometer Array

A linear array of eight magnetometer sensors (G-822ROV/A, Geometrics, Inc.) is towed over large areas (25 acres/day) by the MTADS tow vehicle, pictured in Figure 1. The trailer is constructed from composite materials and aluminum to minimize the magnetic signature of the trailer. The metal beads have been removed from the tires and replaced with a polymer band for the same reason. Each magnetometer measures the local magnetic field of the Earth at the sensor. The sensors are sampled at 50 Hz, and typical surveys are conducted at 6 mph; this results in a sampling density of ~6 cm along track with a horizontal sensor spacing of 25 cm. The nominal ride height of the sensors is 25 cm above the ground.

2.1.3 MTADS EM61 MkII Array

The EM61 MkII MTADS array is an overlapping array of three pulsed-induction sensors specially modified by Geonics, Ltd. based on their EM61 MkII sensor with 1 m×1m sensor coils. The array and the tow vehicle are shown in Figure 2. The nominal ride height of the bottom coils is 33.5 cm above the ground. The EM61 MkII transmits a short EM pulse into the Earth. Metallic objects interact with this transmitted field, inducing secondary fields in the object. These secondary fields are then detected by the sensor receiver coils.

Figure 2. MTADS EM61 Array Pulled by the MTADS Tow Vehicle.

The sensors have been modified to make them more compatible with vehicular survey speeds and to increase their sensitivity to small objects. The array is operated with the three transmitters synchronized to generate the largest possible transmit moment. See Reference 2 for further details about the sensors. MTADS surveys are typically performed using the differential mode, and this mode was used for this demonstration. Nominal survey speed is 3 mph and the sensor readings are recorded at 10 Hz. This results in a down-track sampling of ~15 cm and a cross-track interval of 50 cm.

2.1.4 Pilot Guidance System

The GPS positioning information used for data collection is shared with an onboard navigation guidance display and provides real-time navigational information to the operator. The guidance display was originally developed for the airborne adjunct of the MTADS system (Airborne Multi-Sensor Towed Array Detection System [AMTADS]) [3] and is installed in the vehicle and available for the operator to use. Figure 3 shows a screenshot of the guidance display configured for vehicular use. An integral part of the guidance display is the ability to import a series of planned survey lines (or transects) and to guide the operator to follow these transects. The pilot guidance display can also be used to guide the operator to the survey area and provide immediate feedback on progress and data coverage.

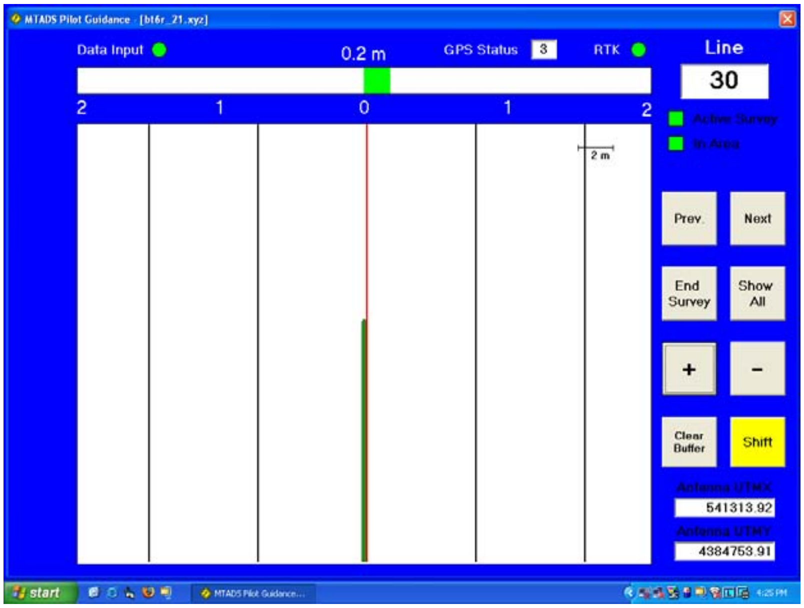

Figure 3. Screenshot of MTADS Pilot Guidance Display.

2.1.5 Man-Portable, Litter-Carried EM61 MkII System

Portions of two demonstrations were conducted using a MP, litter-carried EM61 MkII (MP EM) system developed as an adjunct of the NRL MTADS. The system is designed to survey modest areas (2 acres/day) with a single standard EM61 MkII metal detector (0.5m×1m). The complete system as demonstrated at the Victorville WAA demonstration site is shown in Figure 4. The sensors are sampled at 10 Hz and surveys are conducted at typical walking speed, ~2 mph (1 m/s). This results in a sample spacing of approximately 10 cm down track. See Reference 2 for details on the sensor timing parameters.

Figure 4. MP, Litter-Carried EM61 MkII Sensor System.

The sensor position is measured in real time at 10 hz using the same RTK GPS receivers as the towed arrays. A submeter-level, code-phase GPS receiver (Trimble Ag132) was used under dense tree canopies, as required. Within the context of WAA, the lower positional accuracy can be an acceptable tradeoff for enhanced site coverage [4]. Navigation during data collection was accomplished using a Wide Area Augmentation System (WAAS)-enabled handheld GPS receiver (meter-level, Garmin) and the built-in point-to-point navigation software.

2.2 PROCESS DESCRIPTION

2.2.1 Data Analysis Methodology

The collected raw data are preprocessed on site for quality control (QC) purposes using standard MTADS procedures and checks. Any discrepancies are flagged for the data analyst to address. Next, the data are imported into a single Oasis montaj (Geosoft, Inc.) database using custom scripts developed from the original MTADS Data Analysis System (DAS) routines, which have been extensively validated. As part of the import process, any data corresponding to a sensor outage are marked to not be processed further. Any long wavelength features such as large-scale geology or slow sensor drift are filtered from the data (demedianed or leveled).

The first few data sets collected on site are examined and an empirical threshold is chosen for anomaly selection. The appropriateness of the choice is monitored throughout the demonstration. A built-in feature of Oasis montaj is then used to extract peaks above the empirically determined threshold from the data. The detected anomaly locations, along with the signal magnitude at the peak of the anomaly, are provided daily to the ESTCP Program Office, PNNL, and SNL for the previous day's survey results. The down-sampled transect course-over-ground (COG) (6-10 m spacing) data are also provided. The data analysis work flow is shown pictorially in Figure 5. Additional details on the methodology and its development are available in Reference 5. The located demedianed data are also provided for archival purposes. A similar methodology is used for the analysis of the MP data. See Reference 5 for further information.

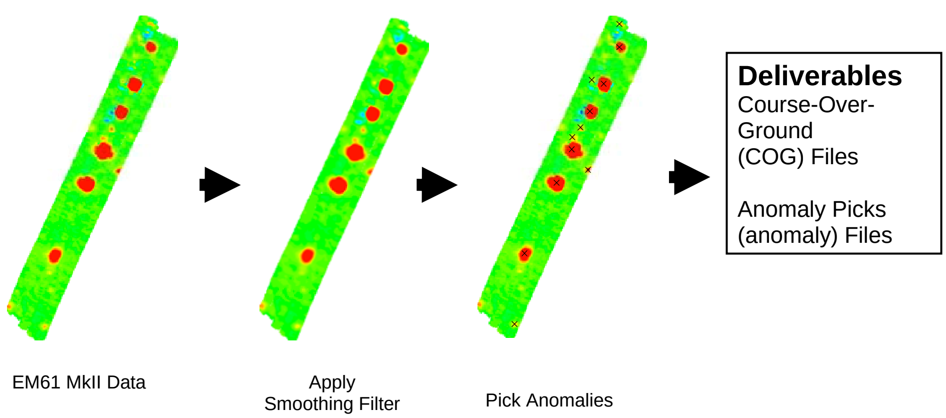

Figure 5. Automatic Anomaly Detection Scheme for the EM61 MkII Array.
(Example data are from the calibration lane at Former Camp Sibert Site 18. EM data are shown on a ±30 mV vertical scale.)

2.3 PREVIOUS TESTING OF THE TECHNOLOGY

The Chemistry Division of the NRL has participated in several programs funded by the Strategic Environmental Research and Development Program (SERDP) and ESTCP, whose goal has been to enhance the detection and the discrimination abilities of the MTADS for both the magnetometer and EM-61 array configurations. The process was based on making use of the location information inherent in an item's magnetometry response and the shape and size information inherent in the response to the time-domain EM induction (EMI) sensors that are part of the baseline MTADS in either a cooperative or joint inversion. The results from the survey of the Target S1 at Isleta Pueblo, New Mexico, [6] are characteristic of the past performance of the MTADS magnetometer platform. As part of ESTCP Project UX-199812, a demonstration was conducted on a live-fire range, the L Range at the Army Research Laboratory's Blossom Point Facility [7]. In 2001, a second demonstration was conducted at the Impact Area of the Badlands Bombing Range, South Dakota, [8] as part of ESTCP Project 4003. The EM61 is a time-domain instrument with either a single gate to sample the amplitude of the decaying signal (MkI) or four gates relatively early in time (MkII). The first generation of the MTADS EM61 MkII array was demonstrated in 2001 [8] at the Badlands Bombing Range with little demonstrable gain over the single decay of the MkI array. A second generation of the MkII array with updated electronics was constructed in 2003 as part of ESTCP Project 200413. The upgraded MTADS EM61 MkII array was demonstrated at both Standardized UXO Technology Demonstration Sites located at the Aberdeen and Yuma Test Centers in 2003 and 2004 [9]. Appendix A of Reference 2 summarizes the Open Field scenario results of the Aberdeen Proving Ground (APG) demonstration. Reference 9 compares the detection-only performance of the MTADS magnetometer, the second-generation MTADS EM61 MkII, and the MTADS GEM-3 Frequency-Domain EMI Sensor Array (GEMTADS) (a frequency-domain EMI sensor) to other demonstrators at both Standardized UXO Technology Demonstration Sites. All three sensor arrays were also demonstrated in the spring of 2007 as part of the ESTCP UXO Discrimination Study at the Former Camp Sibert [10]. Data processing and the development of performance results for the various discrimination methodologies of the UXO Discrimination Study are currently ongoing. The MP EM61 MkII system was successfully demonstrated for WAA and total-coverage surveys at the Victorville WAA demonstration site in the fall of 2006 [11]. A magnetometer MP system was demonstrated at the Dalecarlia AOI6 site in December 2006 [4].

2.4 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

On large open ranges, the vehicular MTADS provides an efficient survey technology. Surveys with the magnetometer array often exceed production rates of 20 acres per day. UXO items with gauges larger than 20 mm are typically detected to their likely burial depths. The detection performance of the MTADS magnetometer and EM61 MkII arrays for the range of munitions types and sizes emplaced at the Standardized UXO Demonstration sites are documented in References 9 and 10 and the references within. This process has to date involved a human operator manually selecting the data corresponding to individual anomalies. Each data segment is then processed by a physics-based algorithm incorporated into the MTADS DAS software or the equivalent UX-Analyze.

While this methodology has proven highly successful in the past, it is not fast enough to support the rapid data requirements for the transect surveys to be conducted as part of the ESTCP WAA

Pilot Project. A faster, more automated method has been developed and was demonstrated as part of this project. The towed-array systems have been successfully demonstrated with magnetometer [13, 15] and EM [2] sensors. MP adjuncts have been successful demonstrated with EM [2, 11] and magnetometer [4] sensors. The location and amplitude of detected anomalies with amplitude above an empirically determined threshold were reported to the ESTCP Program Office, PNNL, and SNL along with the survey COG for reference in near-real-time. This rapid feedback of information allowed for the interactive planning and execution of additional transects and total-coverage surveys for validation purposes while the demonstrations were ongoing and the field team was still deployed.

The presence of certain terrain features such as deep ravines without good crossing points, thick clusters of trees, and other non-navigable features such as steep hill faces can limit the areas that can be surveyed. The presence of long barbed-wire fences without gates and deep ravines and steep hill and plateau faces without good access points can also slow survey operations by reducing survey line length and increasing travel time to traverse these obstacles. These features can also limit access all together. The MP systems with their enhanced maneuverability were deployed in these areas, as required. In part, the enhanced maneuverability of the MP systems comes from the use of a submeter level GPS receiver to operate under the tree canopy when necessary.

3.0 DEMONSTRATION DESIGN

3.1 PERFORMANCE OBJECTIVES

Performance objectives for the demonstrations are given in Table 1 and Table 2 to provide a basis for evaluating the performance and costs of the technology to be demonstrated. Table 1 covers the primary performance objectives of these demonstrations relating to the detection of AOI within the overall survey area. Table 2 contains secondary demonstration objectives/metrics relating to the extraction of additional information about the detected AOIs and the anomalies within those areas. These objectives are for the technology being demonstrated only. The final column in Table 1 and Table 2 indicate whether or not the performance objectives were met. More detailed discussion can be found in Sections 4.3 and 4.4. Overall project objectives are discussed in the WAA Pilot Project Final Report [12].

Table 1. Primary Transect Performance Objectives/Metrics and Confirmation Methods.

Type of Performance Objective	Performance Criteria	Expected Performance (Metric)	Performance Confirmation Method	Objective Met?
Primary Metrics (Relating to Detection of Target Areas and Target-free Areas)				
Qualitative	Reliability and robustness	General observations	Operator feedback and recording of system downtime (length and cause)	See Section 4.3.1
	Terrain/ vegetation restrictions	General observations	Correlation of areas not surveyed to available data (topographical maps, etc.)	See Section 4.3.1
Quantitative	Survey rate	Varies with system Mag. array: 30 lane km/day EM array: 16 lane km/day MP: 10 lane km/day	Calculated from survey results	Yes, except for EM array
	Data throughput	All data from day x processed for anomalies and submitted by end of day x+1	Analysis of records kept/log files generated while in the field	Yes
	Percentage of assigned coverage completed	>95% as allowed by topography	Calculated from survey results	Yes
	Transect location	95% within 10 m of requested transects	Calculated from survey results	No

Table 2. Secondary Transect Performance Objectives/Metrics and Confirmation Methods.

Type of Performance Objective	Performance Criteria	Expected Performance (Metric)	Performance Confirmation Method	Objective Met?
Secondary Metrics (Relating to Characterization of Target Areas)				
Qualitative	Ability of analyst to visualize targets from survey data	All targets in survey area identified	Data analyst feedback and comparison to total-coverage data/other demonstrators results	Yes
Quantitative	Location of inverted targets	Horizontal: < ±0.15 m Vertical: < 30% for depths ≥30 cm < ± 15 cm for depths < 30 cm	Validation sampling (100% survey) and/or remediation sampling (digging)	Yes
	Signal-to-noise ratio (SNR) for calibration items	System response to standard munitions types measured on site are within physics-based bounds	Comparison of calibration item response to documented response curves (most favorable to least favorable response)	Yes
	Data density	Varies with system 10-60 pts/m^2	Calculated from survey results	Yes

3.2 SELECTION OF TEST SITES

Demonstration site selection was conducted by the ESTCP Program Office and the WAA Advisory Group based on the archival literature (e.g., CSM) and other factors. The ESTCP WAA Pilot Project Final Report [12] describes the selection process. The Pueblo Precision Bombing and Pattern Gunnery Range #2 and Victorville Precision Bombing Ranges (PBR) Y and 15 demonstration sites were selected as initial demonstration sites for this project. The more challenging Former Camp Beale site was selected for this project in the second year of the WAA Pilot Project.

3.3 DEMONSTRATION SITE HISTORY AND CHARACTERISTICS

3.3.1 Pueblo Precision Bombing and Pattern Gunnery Range #2

This section briefly summarizes the site history of the Pueblo PBR #2 WAA demonstration site. Further information is available in the WAA Pilot Project Final Report [12] and the Demonstration Data Report [13]. The former Pueblo Precision Bombing and Pattern Gunnery Range #2 (Pueblo PBR #2) is located in Otero County, Colorado, approximately 20 miles south of the town of La Junta, Colorado [14]. The former training range encompasses approximately 68,000 acres and consists of a bombing camp with two runways and nine precision bombing targets, a suspected 75mm air-to-ground target, along with an air-to-ground pattern gunnery range. This area was used for cattle grazing until the War Department assumed control of the lands in 1942. The WAA Pilot Project demonstration area encompasses approximately 7,400 acres of the overall Pueblo PBR #2 site and includes Targets 3 and 4 along with the Suspected 75mm Range AOI. See Reference 14 for additional discussion.

3.3.2 Victorville PBRs Y and 15

This section briefly summarizes the site history of the Victorville PBRs Y and 15 WAA demonstration site. Further information is available in the WAA Pilot Project Final Report [12], the Demonstration Data Report [15], and the MP EM Demonstration Data Report [11].

The Victorville WAA Demonstration site includes the former Victorville PBRs Y and 15. These Ranges are two targets within a much larger complex of bombing targets that are the Victorville FUDS. According the Archives Search Report (ASR) for the Victorville FUDS, the Victorville PBRs Y and 15 are part of a bombing target complex of approximately 23 targets for the training of both pilots and bombardiers of the Army Air Force West Coast Training Center. The Victorville Army Flying School Bombing Ranges (East and North ranges) were part of the Advanced Twin Engine Bombardier School and the Advanced Flying School #4 located at Victorville Army Air Base. The ranges were used from 1942-1945. Most of the 23 bombing targets were used for precision bombing practice using aiming circles. A Certificate of Clearance (COC) issued on October 20, 1947 states the land use is “suitable for grazing and/or mining only” and referred to a number of targets within the larger Victorville Munitions Response Area (MRA).

The Victorville WAA Pilot Project Demonstration site encompasses approximately 5,500 acres of the Victorville FUDS. Victorville PBR Y consists of 4,862 acres and the adjoining PBR 15 comprises 640 acres. The two targets are located approximately 42 miles southeast of the town of Victorville, California.

3.3.3 Former Camp Beale

The following subsections summarize the site history of the Former Camp Beale WAA demonstration site and briefly discuss the demonstration. Further information is available in the Former Camp Beale Site Inspection Results [16], the WAA Pilot Project Final Report [12], and the Demonstration Data Report [2].

The Former Camp Beale FUDS consists of 87,672 acres approximately 20 miles east of Marysville, California, in both Yuba and Nevada counties [16]. Beale Air Force Base (AFB) currently occupies approximately 23,104 acres. Former Camp Beale encompasses land in numerous sections of Townships 14 and 15 North and Ranges 5 and 6 East.

The U.S. government purchased 87,000 acres in 1942 for a training post for the 13th Armored Division. Camp Beale also held training facilities for the 81st and 96th Infantry Division, a 1,000-bed hospital, and a prisoner of war camp. As a complete training environment, Camp Beale had tank maneuvers, mortar and rifle ranges, bombardier-navigator training, and chemical warfare classes. During WWII, Camp Beale had 60,000 personnel. In 1948, Camp Beale became Beale AFB; its mission was to train bombardier-navigators in radar techniques. The base established six bombing ranges of 1,200 acres each. The U.S. Navy also used Beale AFB for training. From 1951 on, Beale trained navigation engineers and ran an Air Base Defense School. These additional activities led to the rehabilitation of existing base facilities and construction of rifle, mortar, demolition, and machine gun ranges. In 1958 the first runway was operational. One year later, the installation ceased being used as a bombing range and the U.S. government

declared portions of Camp Beale/Beale AFB as excess, eventually transferring out 60,805 acres. On December 21, 1959, 40,592 acres on the eastern side of the base were sold at auction. An additional 11,213 acres were transferred to the State of California between 1962 and 1964, and now comprise the Spenceville Wildlife and Recreation Area. In 1964-1965, another 9,000 acres were sold at auction.

The 2006 WAA demonstration area was limited to approximately 18,000 of these acres. An area was chosen that overlaps with a number of historic ranges, has suitable topography to give further insight into the applicability of the WAA techniques, and faces the highest development pressure of any part of the FUDS project. The WAA site encompasses a large, rolling area in the northwest that is relatively free of tall vegetation and two valleys in the Spenceville Wildlife and Recreation Area that are bounded by trees and hillier terrain. The WAA site contains a number of the targets used during the period 1948 through 1959. At present, the WAA site is used almost exclusively for recreation and cattle grazing. A large portion is located in the Spenceville Wildlife and Recreation Area. The remainder is in private hands. A portion of the open area in the NW part of the site has been assembled for development but is currently being used for cattle grazing.

3.4 MOBILIZATION

3.4.1 Logistics

The MTADS vehicular system was mobilized to each demonstration site in a U.S. Navy-owned 53-ft trailer. Harris Transportation Company, a government-contract transportation firm, delivered the trailer to the demonstration site prior to the arrival of the field team on site. Due to the remoteness of the demonstration areas, Nova Research made provisions to acquire the necessary support services from local rental firms. Typically, an office trailer was provided for data analysis and equipment storage. A second 8-ft×40-ft trailer was used to garage and provide secure storage of the MTADS vehicle and sensor platform. Power to the trailers was provided by a diesel field generator (50 kW range) that was also used to recharge the vehicle, radios, and GPS batteries overnight. Communications among on-site personnel was provided by handheld VHF radios. The availability of cellular phone communications on site was non-continuous but was available in portions of each site. Fuel storage was provided for the generator and portable toilets for all field and office crews. In two cases, additional 8-ft×40-ft trailers were provided for working in remote portions of the site. Further details are provided in the individual Demonstration Data Reports [2, 11, 13, 15].

3.4.2 Demonstration Setup

Upon arrival on site, the field team personnel unpacked the 53-ft trailer and established the base camp. The RTK GPS base station receiver and radio link were set up on one of the available established control points. Specific details are provided in the individual Demonstration Data Reports. The sensor systems were then assembled and tested for proper operation along with the operational state of the RTK systems.

3.4.2.1 Calibration Lanes and Objects

A calibration lane of common munitions and munitions simulants were emplaced at each demonstration site. Prior to emplacement, a multipass survey of the proposed area was conducted to ensure that the area was quiet in terms of geology and compact anomalies. Once the items were emplaced and photographed, the positions of each item's nose and tail were recording using RTK GPS. The holes were refilled with the removed material and leveled. The calibration lane was surveyed twice each day that transect data was collected. Further details are available in the individual Demonstration Data Reports.

3.4.2.2 Periods of Operation

The schedules of field work for each demonstration are summarized below in Table 3. The reported duration period reflects the total time in the field, which included other data collection activities in addition to transects. Further details are available in the respective Demonstration Data Reports.

Table 3. Summary of Demonstration Periods.

Demonstration Site	Start Date	End Date	Duration (wks)	Transect lane-km	Number of Detected Anomalies
Pueblo PBR #2	August 30, 2005	October 22, 2005	5.5	300	2,603
Victorville PBRs Y & 15 Veh.	March 20, 2006	March 31, 2006	2	185	1,910
Victorville PBRs Y & 15 MP	October 1, 2006	October 10, 2006	1.5	57	475
Former Camp Beale Veh.	May 21, 2007	June 22, 2007	5	225	5,779
Former Camp Beale MP	May 28, 2007	July 6, 2007	6	178	3,631

3.5 DEMOBILIZATION

At the end of vehicular field operations, all equipment, materials, and supplies were repacked on the 53-ft trailer and secured. Harris Transportation Company, a government contract transportation firm, transported the trailer from the site to the MTADS home base at the Army Research Laboratory (ARL) at Blossom Point, Welcome, Maryland. When the survey completion date could be estimated with some confidence, the local vendors were contacted to remove the logistics items. At the end of the MP field operations, all equipment, materials, and supplies was repacked and return shipped via a traditional shipping company (FedEx).

3.6 ANALYTIC PROCEDURES

The precision collection of high SNR data using the MTADS platform is a mature technology. The rapid and accurate extraction of anomaly location and a measure of anomaly amplitude from high-volume transect data is the novel component of this series of demonstrations. To accomplish this task, an automated methodology was required. Such a methodology has been developed and is discussed in detail in Reference 5.

Briefly, an anomaly extraction threshold is determined based on the site-specific dynamic background floor. When the first survey results from a calibration strip (if available) and several early transect data sets at the site are available, these data are used to determine the dynamic noise level at the site from quiet portions of the data. Starting with an anomaly extraction threshold equal to the dynamic background level, the anomaly extraction threshold is increased in increments of dynamic background level, and the site-specific anomaly extraction threshold is determined. For the WAA magnetometer array demonstrations, anomaly extraction is done using the analytic signal (AS, nanoTesla [nT]/m) instead of the total field measurements. Unlike the dipolar response of the total field, the analytic signal response is monopolar with the peak at the center of the anomaly.

As an example, for the Former Camp Beale demonstration, five of the first towed-array transect data sets from the site were analyzed in the described manner. The fall-off behavior for the data sets is shown in Figure 6. Based on experience from determining the extraction thresholds from other demonstrations and the fall-off behavior, a peak extraction threshold of 40 mV, S1 was selected. While the validity of this decision was monitored throughout the demonstration, no changes were made to the anomaly extraction threshold for the vehicular system.

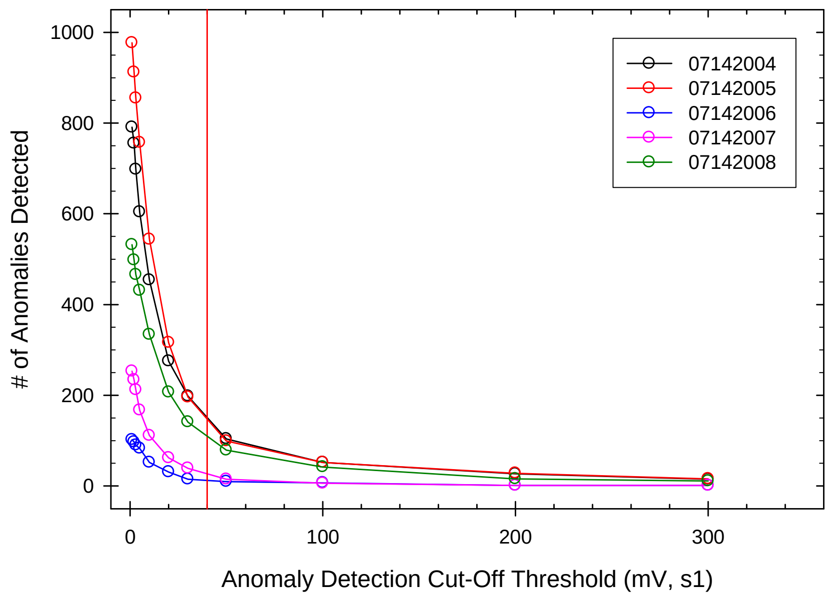

Figure 6. Peak Anomaly Cut-Off Threshold Analysis for the 07142 Vehicular Data Sets from Former Camp Beale.

(The red line indicates the result for the final parameter value, 40 mV, S1.)

The same methodology was used for the MP EM system in this demonstration. A peak extraction threshold of 7 mV, S1 was initially selected. The validity of this decision was monitored throughout the demonstration, and on June 21, 2007, it was decided in cooperation with the Project Manager, PNNL, and SNL to adjust the threshold upwards to 15.5 mV, S1 to provide better correspondence with the vehicle system results. The analysis results, shown in

Figure 7, indicate that a MP threshold of 15.5 mV, S1 yields the same number of anomalies/km as the vehicular system with a threshold of 40 mV, S1 for the entire data collection.

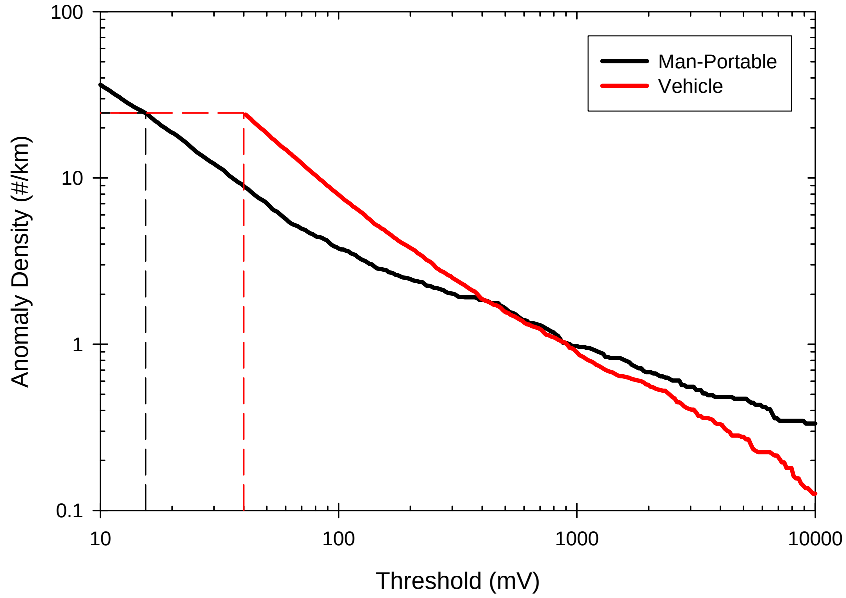

Figure 7. Comparison of MP EM and Vehicular Anomaly Extraction Results.
(Anomaly density [anomalies/km of transect] is plotted versus anomaly extraction threshold (mV, S1). The dashed lines indicate the final threshold values.)

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4.0 PERFORMANCE ASSESSMENT

4.1 PERFORMANCE DATA

Two examples of the types and quality of data collected as part of this demonstration are discussed in the following two sections.

4.1.1 Transect Data Collection

The main focus of the demonstrations was the collection of transect data following the transect plans developed by PNNL based on the archive data (CSM) [14, 16] and WAA Pilot Project goals as outlined in the WAA Pilot Project Final Report [12]. At each of the demonstration sites, the site was surveyed with final site coverage of 1-2%. The transect results from the Former Camp Beale demonstration are shown in Figure 8.

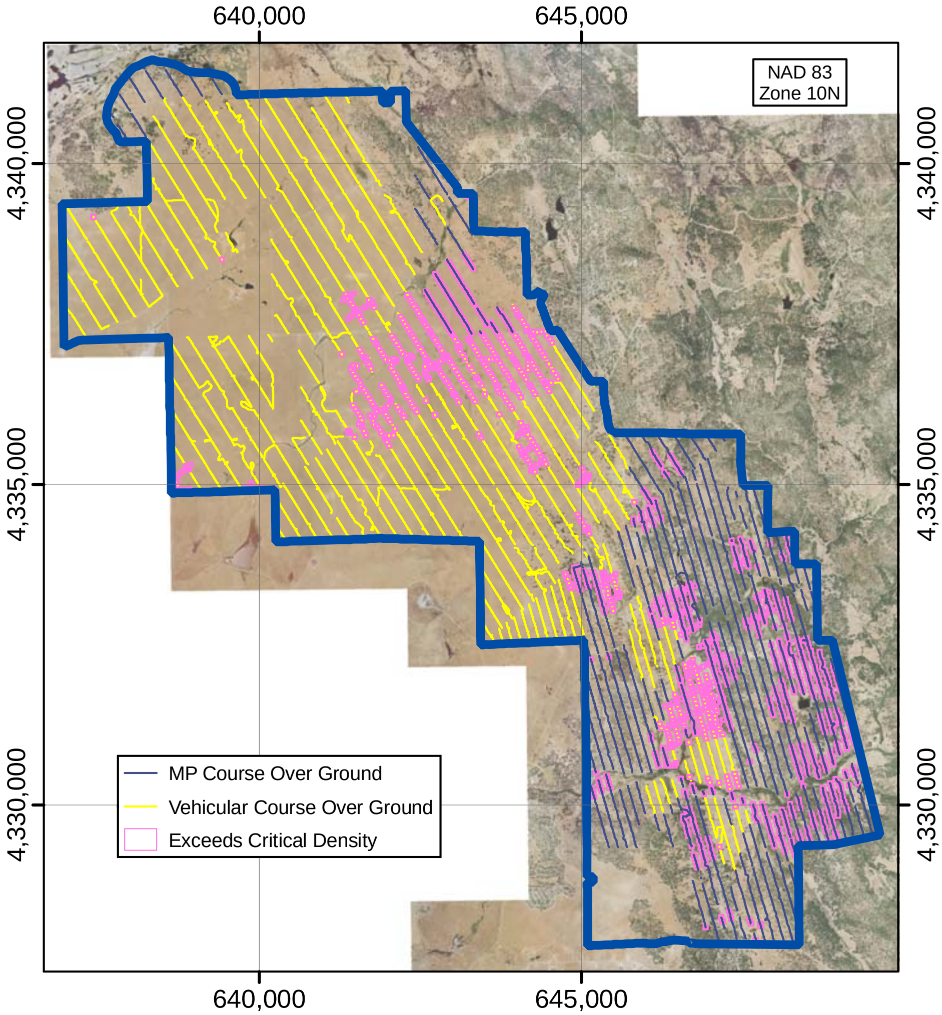

Figure 8. Map Showing the Transect Survey Results for the Former Camp Beale Demonstration.

(Vehicular and man-portable transect COGs are shown as yellow and blue lines, respectively. Areas with anomaly densities that exceed the critical density are highlighted in pink.)

The small number of large gaps in transect coverage reflect areas within the demonstration site that were not accessible due to right-of-entry issues. The results in terms of fractional site coverage for each demonstration are given in Table 4.

Table 4. Demonstration Site Parameters and Fractional Coverage.

Demonstration Site	MRA Size (acres)	System	WAA Demonstration Site Size (acres)	Fractional Transect Coverage (%)
Pueblo PBR #2	**68,000**		**7,400**	**1.9**
Victorville PBRs Y&15	**5,120**	**Total**	**5,400**	**2.0**
		Vehicle mag		1.7
		MP EM		0.3
Former Camp Beale	**87,000**	**Total**	**18,000**	**0.8**
		Vehicle EM		0.6
		MP EM		0.2

The towed-array EM system covered 225 lane-km of the PNNL transect plan for the Former Camp Beale demonstration. The MP system covered an additional 178 lane-km. Additional details are available in the Demonstration Data Report [2]. The position (easting, northing) and signal strength (peak signal [S1, mV]) were extracted for each anomaly above the empirical threshold independently determined for each system. Vehicular and MP transect COGs are shown as yellow and blue lines, respectively. Areas with anomaly densities that exceed the critical density are highlighted in pink. See Reference 12 for further details on anomaly density analysis. The total acreage covered by transect surveys was 155 acres, or approximately 0.8% of the total 18,000 acre site.

4.1.2 Anomaly Density Falloff Analysis for Known Targets

One focus of the total coverage surveys conducted as part of these demonstrations was to map the anomaly density fall-off as a function of distance from the known targets. Once the total coverage data had been collected and analyzed in the MTADS DAS, the data were divided into cells in a radial leading from the center of each target. The number of anomalies in each cell was counted. Such analyses were conducted for Pueblo PBR #2 Targets 3 and 4 as well as the Victorville PBR #15 Target. For the Victorville PBR #15 Target, the data were divided into non-overlapping bands 30-m thick (in radial distance) and with increasing radial distance from the center of the PBR #15 Target oriented to the South. The number of anomalies in each band was counted and is shown in Figure 9.

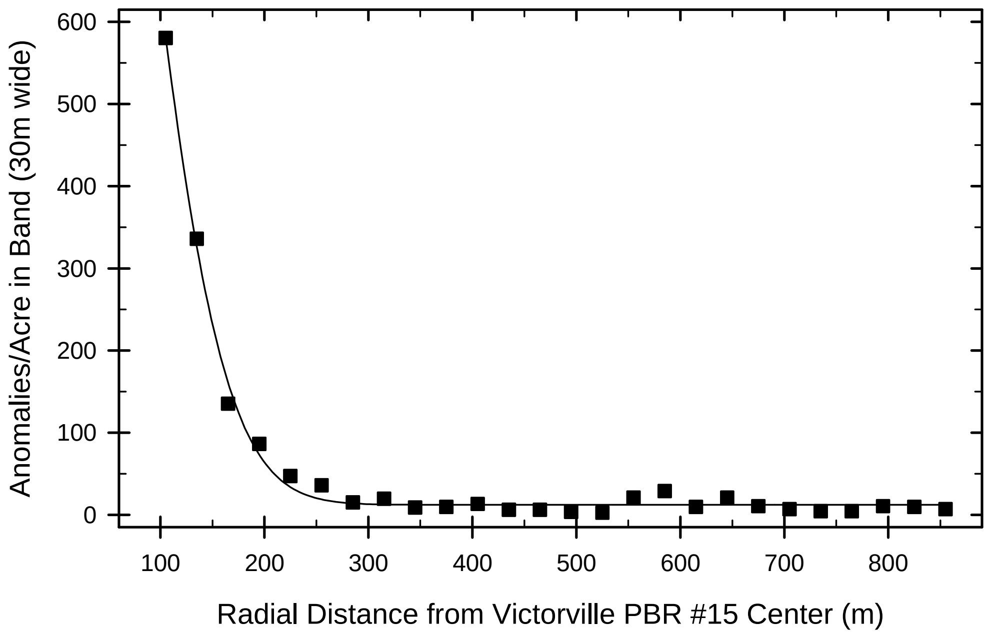

Figure 9. Number of Anomalies Per Acre as a Function of Radial Distance from the Victorville PBR #15 Target Center as Located via GPS on Site.
(Bands with increasing radial distance and 30-m width [radial distance] were used to bin the anomalies. The solid line is the results of a fit to a normal distribution with a persistent background value of 12.2 anomalies/acre.)

Assuming that the anomaly density around a target falls off according to a normal distribution, the results can be fit to a normal distribution with a persistent background value, or

$$y = y_0 + ae^{-\frac{1}{2}\left(r/b\right)^2}$$

Such a fit is shown in Figure 9 as a solid line. The fit parameters for Victorville PBR #15 and Pueblo PBR #2 Targets BT3 and BT4 are given in Table 5. One of the fit parameters, y_0, is a persistence component reflective of the background anomaly density for each site. The coefficient *b*, which accounts for the falloff, is two to four times smaller for the Victorville PBR #15 Target than those values seen at Pueblo PBR #2.

Table 5. Fit Parameters for Victorville PBR #15 and Pueblo PBR #2 Targets.

Fit Parameter	Victorville PBR #15	Pueblo PBR#2 BT3	Pueblo PBR#2 BT4
a	1417	63	152
b	78	148	288
y_0	12.2	8.2	6.2

4.2 PERFORMANCE CRITERIA AND CONFIRMATION METHODS

The project performance criteria for the demonstration were introduced in combination with the project performance objectives in Table 1 and Table 2 in Section 3.1 of this document. Modification to some performance objectives and metrics has occurred during the evolution of the WAA Pilot Project. Table 6 and Table 7 summarize the results for the individual performance criteria. Sections 4.3 and 4.4 provide additional details on the results for each individual criterion.

Table 6. Primary Transect Performance Objectives/Metrics and Confirmation Methods.

Type of Performance Objective	Performance Criteria	Expected Performance (Metric)	Performance Confirmation Method	Objective Met?
Primary Metrics (Relating to Detection of Target Areas and Target-free Areas)				
Qualitative	Reliability and robustness	General observations	Operator feedback and recording of system downtime (length and cause)	Yes, see Section 4.3.1.
	Terrain/ vegetation restrictions	General observations	Correlation of areas not surveyed to available data (topographical maps, etc.)	Yes, see Section 4.3.1.
Quantitative	Survey rate	Varies with system Mag. array: 30 lane km/day EM array: 16 lane km/day MP: 10 lane km/day	Calculated from survey results	Mag. array: 32 lane km/day EM array: 8 lane km/day MP: 11 lane km/day
	Data throughput	All data from day x processed for anomalies and submitted by end of day x+1	Analysis of records kept/log files generated while in the field	All results submitted on schedule
	Percentage of assigned coverage completed	>95% as allowed by topography	Calculated from survey results	100%
	Transect location	95% within 10 m of requested transects	Calculated from survey results	Mag. array: 93% EM array: 88% MP: 98%

Table 7. Secondary Transect Performance Objectives/Metrics and Confirmation Methods.

Type of Performance Objective	Performance Criteria	Expected Performance (Metric)	Performance Confirmation Method	Objective Met?
Secondary Metrics (Relating to Characterization of Target Areas)				
Qualitative	Ability of analyst to visualize targets from survey data	All targets in survey area identified	Data analyst feedback and comparison to total-coverage data/other demonstrators results	Yes, see Section 4.4.1.
Quantitative	Location of inverted targets	Horizontal: < ±0.15 m Vertical: < 30% for depths ≥30 cm < ± 15 cm for depths <30 cm	Validation sampling (100% survey) and/or remediation sampling (digging)	No horizontal validation data was collected. Vertical: Depths ≥30 cm: -10 cm, or 10% shallow Depths < 30 cm: -1.0 ± 15 (1σ) cm
	SNR for calibration Items	System response to standard munitions types measured on site are within physics-based bounds	Comparison of calibration item response to documented response curves (most favorable to least favorable response)	Yes, See Section 4.4.2.
	Data density	Varies with system 10-60 pts/m^2	Calculated from survey results	Mag. array: 65 pts/m^2 EM array: 10 pts/m^2 MP: 11 pts/m^2

4.3 DATA ASSESSMENT

4.3.1 Primary Qualitative Performance Objectives

Reliability and Robustness: The MTADS tow vehicle and magnetometer array are designed for off-road operations in rugged terrain with demonstrated operational success in a variety of desert [6] and plains/grasslands environments [3]. Participation in the WAA Pilot Project called for continuous cross-country operations for several weeks at a time. The accumulated punishment of this survey style on the MTADS systems was non-trivial. Several identified changes or upgrades were made over the duration of the project to further enhance the reliability and robustness of the systems.

Terrain/Vegetation Restrictions: On large open ranges, the vehicular MTADS provides an efficient survey technology. Surveys with the magnetometer array often exceed production rates of 20 acres per day. The presence of certain nonnavigable terrain features such as ravines without good crossing points, concentrated boulder fields, and other nonnavigable features such as the combination of steep rises with loose, sandy soils limited the areas that could be surveyed

with the vehicular system. The presence of fence lines with limited access between areas can also limit efficiency by breaking survey lines into smaller portions, which are inherently less efficient as more and more time is spent driving between transects and not collecting data. Refer to Section 4.1.1 of Reference 5 for further details.

4.3.2 Primary Quantitative Performance Objectives

Survey Rate: The original performance metric, 30 acres/day (60 lane-km/day) for towed-array magnetometers, has proven unrealistic for a towed array system on these types of sites. Table 8 gives the average daily survey rates for the vehicular towed array and MP systems for each demonstration. Based on ongoing experience during the project, a revised metric of 15 acres/day (30 lane-km/day) for the towed-array magnetometer system was adopted. The MP EM system was not part of the original project design, and metrics were developed at the time of introduction. The MP EM system has a much lower rate of advance, and the expected survey rate was set at 10 lane-km/day, or 2.5 acres/day. Similarly, when the EM61 MkII towed-array was introduced for use at Former Camp Beale, metrics of 16 lane-km or 8 acres/day were developed based on the relative rates-of-advance for the EM61 MkII and magnetometer arrays. The Former Camp Beale survey rate results were approximately one-half the original performance metrics listed in the demonstration plan. The terrain and obstructions at Camp Beale were more daunting that the original assessment indicated and necessitated more fractional production from the MP system than anticipated. Due to the length of the Camp Beale field campaign, additional field crews were required and the opportunity was taken to experiment with the transfer of the technology to a commercial partner, NAEVA Geophysics, Inc. The members of the original field team were assigned one each to the field crews provided by NAEVA to provide training, oversight, and perform QC checks on the data to maintain continuity with the data products of the first three demonstrations. While the demonstration was generally a success, the new field crews required a period to become familiar with the stringent expectations of this demonstration, and initial progress was not at the expected rate.

Table 8. Survey Rate by Demonstration Site and System.

Demonstration Site	System	Avg. Lane-km (km/day)	Avg. Area (acres/day)
Pueblo PBR #2	Vehicle mag	22.1 ± 11.2	10.9 ± 5.5
Victorville PBRs Y&15	Vehicle mag	41.8 ± 5.0	20.5 ± 2.5
	MP EM	15.1 ± 3.6	3.7 ± 0.9
Former Camp Beale	Vehicle EM	8.3 ± 5.4	4.1 ± 2.7
	MP EM	6.1 ± 3.0	1.5 ± 0.7

Data throughput: Success for this performance metric, simply stated, required that all transect results are transmitted to the Program Office, PNNL, and SNL within 24 hours of data collection for the survey. This was accomplished for all of the demonstrations except the Victorville MP EM demonstration. Due to the short deployment for the Victorville MP EM demonstration, the results were submitted immediately after the demonstration at the agreement of all parties.

Percentage of Assigned Coverage Completed: The performance metric for this objective was “>95% as allowed by topography.” Every transect from every transect plan was attempted in its

entirety, in some cases in multiple sections and from multiple directions. This corresponds to 100% coverage, as allowed by topography.

Transect Location: With respect to this metric, the COG files provided as part of the daily deliverables were used as the data set. The COG files report the location of the center of each sensor platform down-sampled to provide a point every 6-10 m down-track during data collection. Each COG file was then paired with the corresponding planned transect and the position difference calculated for each reported position. See Section 4.1.2 of Reference 5 for a detailed discussion of the analysis. No attempt was made to eliminate data collected during obstacle avoidance. In agreement with PNNL and SNL, such data, which were clearly collected off the transect line, were retained as valuable, useful additional information. Therefore, the results in Table 9 represent an upper limit to the cross-track offset and deviation. For the Former Camp Beale transects, because the transects were not oriented EW or NS, only the magnitude of the cross-track offset was evaluated and not the direction. This artificially increases the calculated average offset because the data are no longer zero-centered.

Table 9. Transect Location Statistics by Demonstration Site and System.

	% within 10 m of transect	Average Cross-Track Offset (m) and Std. Dev. (1σ)
Pueblo PBR #2		
Vehicular mag	91.3	1.0 ± 19.4
Victorville PBRs Y & 15		
Vehicular mag	95.3	-0.3 ± 8.6
Man-portable	99.6	0.4 ± 2.9
Former Camp Beale*		
Vehicular EM	88.4	6.5 ± 21.5
Man-portable	95.6	3.4 ± 6.2

* For the Former Camp Beale transects, only the magnitude of the cross-track offset was considered because the transects were not oriented EW or NS.

4.4 SECONDARY PERFORMANCE OBJECTIVES

4.4.1 Secondary Qualitative Performance Objectives

Ability of Analyst to Visualize Targets from Survey Data: Visual comparison of the AMTADS data collected by Sky Research, Inc. in overlapping areas with the MTADS total coverage areas did not indicate that any anomalies in the AMTADS data were not seen in the MTADS data also. Similarly, a visual comparison of MTADS and AMTADS anomaly picks did not show any significant disagreement. Further discussion is available in Section 4.2.1 of Reference 5.

4.4.2 Secondary Quantitative Performance Objectives

Depth of Inverted Anomalies: The discussion of this performance objective focused on the Pueblo site as no anomalies have been prosecuted at either the Victorville or Former Camp Beale demonstration sites as of the writing of this report. A dig list consisting of items of interest from all available Pueblo PBR #2 data sets was prepared by the ESTCP Program Office, and 621 items were intrusively investigated during the late summer/early fall of 2006. The subset of

anomalies generated by the MTADS system were selected and sorted by fit quality. Of the MTADS-related anomalies that were investigated, 213 had fit quality values of 0.9 or higher and had a complete, unambiguous dig report to allow further analysis. The actual horizontal location of the remediated items was not recorded, so no comparison of horizontal location performance can be performed. The anomalies were partitioned into two categories for analysis, those with predicted depths of 30 cm or greater and those with depths of less than 30 cm. This separation allows the comparison between fit and actual depths for the shallower targets to be expressed in a meaningful fashion, in cm, while allowing a fractional comparison for the deeper anomalies. The average depth difference (Predicted – Actual Depth) for the 157 deep anomalies as determined from the dig list results is -0.02 ± 0.31 (1σ) m. The average fractional difference, (Predicted – Actual Depth) / Predicted Depth is -0.10 or the predicted depths are on average 10% shallow. For the shallow anomalies, the criterion was the absolute depth difference. For the 154 shallow anomalies, the average depth difference was -0.01 ± 0.15 (1σ) m.

SNR for Calibration Items: For demonstrations where the towed arrays were deployed, calibration lanes were emplaced with standard munitions and munitions simulants as described in Section 3.4.2.1. The calibration lanes were surveyed at the beginning and end of each field day that transect survey data were collected. To evaluate the calibration item data, the peak sensor response for each emplaced item from each sortie was determined. A sub-area in between two of the calibration items was identified to be relatively free of anomalies and was used for each data set to extract a dynamic, or driving, background signal level. Further details are provided in the Demonstration Data Reports [2, 11, 13, 15] and the Final Report [5]. As an example, the measured anomaly peak positive response for 155 mm Projectile #2 emplaced in the Pueblo PBR #2 calibration lane and the magnetometer array is shown in Figure 10. The solid line indicates the aggregate average value, and the dashed lines indicate a 1σ envelope. It is likely that the variation shown in Figure 10 represents the difficulty in navigating the sensor array over the exact same path every sortie more than any variability in the sensor response to the emplaced items.

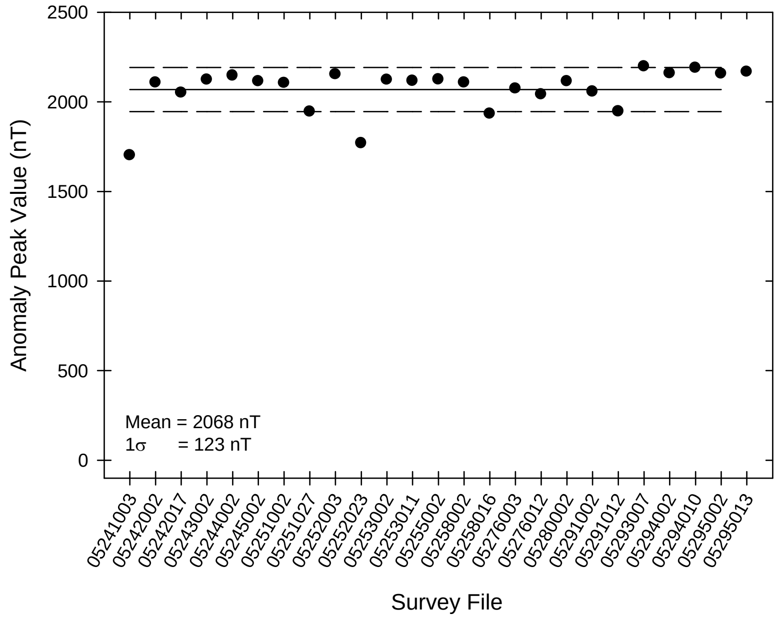

Figure 10. Peak Positive Values from Each Survey for 155-mm Projectile #2 at Pueblo. (The result for each data set is shown in order of acquisition. The horizontal axis is the survey file number. The solid line represents the aggregate average analytic signal, and the dashed lines represent a 1σ envelope.)

The sensor system noise floors were evaluated using the series of static data sets collected each morning. The field day began with a period for system warm up of approximately 15 minutes for the magnetometer array and 30 minutes for the MP EM system. During this time, walk-around preventative maintenance inspections were conducted and the RTK GPS network was established. A data set was then collected for a period of 5-6 minutes while the vehicle was kept stationary and the engine turned off. Every effort was made to minimize the movement of personnel and equipment in the vicinity of the MTADS. The 2-D positioning variation was evaluated by computing the standard deviation of both the northing and easting components of the position data for the entire period and combining them as the square root of the sum of the squares. The standard deviation for the demedianed data from each geophysical sensor was then calculated, and the arithmetic mean was computed for each data set. In occasional cases, an obvious artifact was present in the data (e.g., a vehicle pulls up along side the tow vehicle unannounced) and distorts a portion of the static run. In these cases, only the unperturbed data was used. The results of the static tests at the Pueblo PBR #2 demonstration site are summarized in Table 10.

Table 10. Static Test Data Results for the Vehicular Survey at the Pueblo PBR #2 Site.

Calibration Area	Result Type	Value
North	2-D position	0.42 ± 0.14 cm
	Magnetometer	0.89 ± 0.97 nT
South	2-D position	0.44 ± 0.10 cm
	Magnetometer	0.67 ± 0.72 nT

Data Density: As an example of the system performance for this objective, data density analyses from one transect sortie from each sensor system demonstrated are presented in Table 11. Similar performance can be seen for the entire data archive. Only data which met the MTADS QC requirements were considered for the analyses.

Table 11. Example Transect Data Density Results.

	Vehicular Magnetometer	Vehicular EM	Man-Portable EM
Survey length (m)	3,650	2,312	1,951
# of data points	501,304	45,392	21,383
Data density (pts/m^2)	68	10	11

4.5 TECHNOLOGY COMPARISON

The ESTCP WAA Pilot Program was designed to examine the feasibility of conducting large-scale footprint reduction efforts for UXO on FUDS and other similar sites. Mature technologies were identified that could potentially be successful towards this goal, and these technologies were demonstrated individually and in combinations within the WAA Pilot Program. The WAA Pilot Program Final Report [12] documents these technologies and their respective performance.

5.0 COST ASSESSMENT

5.1 COST REPORTING

The costs considered for these demonstrations have been broken out into three categories; fixed costs (mobilization, demobilization, and reporting); field operations support (data collection and analysis); and on-site logistics. To facilitate comparison to the other technologies demonstrated as part of the ESTCP WAA Pilot Program, Table 12 details the fixed and field-related costs for two standardized demonstrations. The two demonstration scenarios are a 10,000 acre site and a 50,000 acre site.

Table 12. Costs for Two Standardized Towed-Array Magnetometer Survey Scenarios.

	10,000 acres		**50,000 acres**
Fixed costs	80	k$	80
Logistics	4		4
Field work	400	lane-km of transects	2,000
	3	deployment length in weeks	14
	40	k$ / week	40
	120	k$	560
Grand total	204	k$	644
Cost/acre	20.4	$	12.9

It is assumed that transect surveys are conducted with the MTADS magnetometer towed-array and that transect sampling density of 2% is used. The costs presented are based on the composite figures provided in the Pueblo PBR #2 and Victorville PBRs Y and 15 Final Report [5], including an average on-site logistics cost of $4,000. Further details are available in the report.

The recent demonstration at the Former Camp Beale WAA demonstration site has provided a reasonable basis for reporting on the costs and performance associated with the EM towed array and the MP EM adjunct. This demonstration represents the first deployment of the MTADS EM61 MkII array for WAA data collection. The deployment of the MP EM system to the Victorville WAA demonstration site was too limited in scope and duration to allow for extrapolation to the scale of a full deployment. The fixed and the deployed data collection costs for the two systems used at the Former Camp Beale demonstration are given in Table 13. The survey rates for the two EM systems were one-half to one-third that of the magnetometer array. Any sharing of cost elements that were due to the two demonstrations being conducted concurrently were removed from the data presented in Table 13.

Table 13. Summarized Costs of EM WAA Transect Surveys at Former Camp Beale.

	Vehicular	MP
Fixed costs (k$)	79.3	67.1
Field work (k$, total)	179.0	245.9
Field work (k$/wk)	32.5	41.0
Transect coverage (km/wk)	40.9	29.7
Transect coverage (acres/wk)	20.4	7.3

5.2 COST ANALYSIS

There are two main cost drivers for surveys of the types conducted under this project. There are the fixed costs associated with mobilization (to and from the survey site) and the generation of necessary documentation. While the reported figure of $80,000 may seem high at first, there are two significant components to this cost. First is the transportation of the MTADS towed-array systems. The MTADS is transported in a U.S. Navy-owned 53-ft trailer at roughly $10,000 one way. There are also several person-weeks of skilled labor included to generate test plans and survey reports and to maintain the MTADS system. One lesson learned from this demonstration is that the MTADS, a sophisticated research and development platform, is constructed from components that require extensive maintenance to withstand the punishments of demonstrations of this type. See Section 6.3 for further discussion.

Once the equipment and field team are on site, there is a deployment cost associated with running the survey that has been reported in terms of dollars/week. The total cost of data collection is governed by the time in the field, which is governed by the sustainable survey rate. As can be seen from Table 12 and Table 13, the fixed costs of mobilization and documentation are significant when compared to the data collection costs for smaller sites (<10,000 acres). Taking the Pueblo PBR #2 demonstration as an example, 290 lane-km of transect data were collected. Using Table 12, one would estimate that 2-3 weeks of data collection would be required at a cost of $80,000–120,000. The fixed costs for such a deployment are $80,000, or 40-50% of the total cost of the survey.

The cost of the required on-site logistics items was also variable, ranging up to $11,000 for the Former Camp Beale demonstration. The Victorville vehicular demonstration, which had the smallest set of logistics items out of the demonstration, had logistics costs of ~$8,000 because the logistics items came mostly from the Riverside, California, area, a significant travel distance. Local availability of the logistics items can dramatically reduce the cost of having these items on site, as the cost of delivery and servicing can depend on the travel distance.

The fixed costs of a MP-based demonstration are lower, as shown in Table 13, mostly due to not requiring the 53-ft trailer mobilization. However, the survey rate is significantly lower for the MP EM based on rate of advance (0.7-1 m/s versus 1-2 m/s) and on sensor footprint (1 m cross-track versus 2 m). For the Pueblo PBR #2 demonstration, a MP team would require 9.5 weeks to cover the same lane-km and would only have only covered half the acreage.

5.3 COST COMPARISON

The ESTCP WAA Pilot Program was designed to examine the feasibility of conducting large-scale footprint reduction efforts for UXO on FUDS and other similar sites. Mature technologies were identified that could potentially be successful towards this goal, and these technologies were demonstrated individually and in combinations within the WAA Pilot Program. The WAA Pilot Program Final Report [12] documents these technologies and their respective costs.

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6.0 IMPLEMENTATION ISSUES

6.1 COST OBSERVATIONS

Demonstrations of the types outlined in this report have three components: fixed costs associated with mobilization and demobilization, the costs of deploying a team in the field, and logistics costs. The mobilization and demobilization costs were fairly constant across the demonstrations, and include such line items as equipment preparation and shipment, field team travel, and generation of the required documentation. There was one cost that proved to be significantly variable. The shipment of the equipment was a function of travel distance for the vehicular systems ($6,000 to $10,000 one way), and significantly lower for the Victorville MP EM demonstration ($1,200 one way). The costs associated with deploying a survey team in the field was reproducibly approximately $40,000 per week, as team size and per diem were basically constant. The cost of the required on-site logistics items was also variable, ranging up to $11,000 for the Former Camp Beale. For these items, availability and delivery distance are the strong cost drivers.

6.2 PERFORMANCE OBSERVATIONS

In general, the deployed systems met the performance metrics set forward in the Technology Demonstration Plans. The resulting data sets were successfully used to delineate known AOIs within the overall demonstration site. Additional AOIs with similar characteristics were identified for further study. Total coverage survey data were collected in small areas at each site to provide additional characterization of each site. Examples of these results include the determination of the background anomaly densities at each site and the characterization of the anomaly density fall-off as a function of radial distance from known targets. Both of these pieces of information help future planners understand the extent of targets and the contrast for detection of these features from the local background. Ground-based technologies developed for UXO problems, such as the MTADS, are well-positioned to participate in both WAA activities and site characterization/validation activities during the same deployment with the same equipment.

Terrain and other site access issues presented more of a challenge to both survey rate and to site coverage than had been initially expected. Significant portions of the Former Camp Beale and Victorville, California, demonstration sites could not be accessed with the tow vehicle. In the case of the Victorville demonstration site, the geological properties of the northern portion of the site also limited the effectiveness of the magnetometer system. In these cases, the MP EM system was deployed to survey some or all of these areas at the cost of a significantly slower survey rate. For the Former Camp Beale demonstration, all assigned transects for which rights-of-entry were available were surveyed using a combination of the two systems. Initial site visits can help to contain the effects of terrain by providing the necessary information to plan survey strategies in advance.

6.3 SCALE-UP

Sophisticated research and development platforms, such as the MTADS, are designed to support a variety of missions that require far more stringent control over system performance and system

noise floors. One example is the collection of high quality data for the discrimination of UXO from scrap and geology. See Reference 10 for a recent example of this type of demonstration. Systems like the MTADS are constructed from components and to specifications that far exceed what is required for the task of WAA transect data collection. For example, the specialized components used to construct the system are completely non-ferrous when possible and are typically aircraft aluminum, fiberglass, and other composites. These components do not wear as well as typical vehicle components, and extensive maintenance is required to withstand the punishments of demonstrations of this type. Additionally, the capital costs of assembling such a system can be probative to a full-scale operation. A compromise system built from more standard materials and components, integrated in the spirit of the MTADS, may well provide the necessary performance for WAA at a reduced cost. A decreased cost would reduce the barrier to profitably conducting WAA operations either in terms of the minimum quantity of work required to successfully amortize the acquisition of such as system and/or the deployment of multiple systems to decrease field time. Given the statistical sampling nature of transect data collection, a controlled degradation of certain system performance metrics (e.g., background signal level) would not degrade the overall system performance for WAA but would facilitate full-scale deployment.

6.4 LESSONS LEARNED

A lesson learned from the Pueblo PBR #2 demonstration was the value of a brief (2-3 day) site reconnaissance visit by the field team prior to the survey to investigate the site. Such site visits were conducted prior to the Victorville and Former Camp Beale demonstrations and greatly aided in the efficient survey of the site in terms of providing advanced knowledge about hazards to navigation, site conditions, and access routes.

Another lesson learned from the Pueblo demonstration was that the original performance metric for that demonstration, 30 acres/day, for this performance object was unrealistic for a towed array system on this site. Based on the Pueblo and Victorville demonstrations, a reasonable survey rate for magnetometer transect surveys is 16 acres/day (32 lane-km) for sites that are reasonably open to navigation.

6.5 APPROACH TO REGULATORY COMPLIANCE AND ACCEPTANCE

An Advisory Group was assembled from the three services and from state and federal regulatory agencies to aid in acceptance of the overall WAA Pilot Program results by the stakeholders who would be involved in such efforts. The Advisory Group has been involved in the entire process from early planning and site selection to reviewing the Pilot Project Final Report. For each demonstration site, coordination and permitting with the various stakeholders was typically handled at the Pilot Program level. The WAA Pilot Program Final Report [12] documents these issues.

7.0 REFERENCES

Report of the Defense Science Board Task Group on Unexploded Ordnance, Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, Washington, D.C., Nov. 2003.

"EM61 MkII Transect Demonstration at Former Camp Beale Technology Demonstration Data Report," G.R. Harbaugh, D.A. Steinhurst, N. Khadr, T. Furuya, and T.H. Bell, Nova Technical Report NOVA-2031-TR-0004, December 7, 2007.

"Airborne MTADS Demonstration at the Badlands Bombing Range, September, 2001," J.R. McDonald, D.J. Wright, N. Khadr, H.H. Nelson, NRL/PU/6110—02-453.

"Magnetometer Transect Survey of AOI 6 – Dalecarlia Impact Area, American University Experiment Station," Naval Research Laboratory Memorandum Report NRL/MR/6110—07-9063, July 11, 2007.

"Wide Area UXO Contamination Evaluation by Transect Magnetometer Surveys, Pueblo Precision Bombing and Pattern Gunnery Range #2, La Junta, CO, and Victorville Precision Bombing Ranges Y and 15 Victorville, CA," G.R. Harbaugh, D.A. Steinhurst, N. Khadr, Nova Technical Report NOVA-2031-TR-0005, December 21, 2007.

"MTADS Airborne and Vehicular Survey of Target S1 at Isleta Pueblo, Albuquerque, NM, 17 February – 2 March 2003," H.H. Nelson, D. Wright, T. Furuya, J.R. McDonald, N. Khadr, D.A. Steinhurst, NRL/MR/6110—04-8764, March 31, 2004.

"Electromagnetic Induction and Magnetic Sensor Fusion for Enhanced UXO Target Classification," H.H. Nelson and B. Barrow, NRL/PU/6110—00-423, September 15, 2000.

"Advanced MTADS Classification for Detection and Discrimination of UXO," H.H. Nelson, T.H. Bell, J.R. McDonald, B. Barrow, NRL/MR-MM/6110—03-8663, January 31, 2003.

"Survey of Munitions Response Technologies," ESTCP, ITRC, and SERDP, June, 2006.

"MTADS Demonstration at Camp Sibert Magnetometer / EM61 MkII / GEM-3 Arrays," Demonstration Data Report, G.R. Harbaugh, D.A. Steinhurst, N. Khadr, September 26, 2007.

"Wide Area UXO Contamination Evaluation by Transect Magnetometer Surveys, Man-Portable EM Demonstration Data Report, Victorville Precision Bombing Ranges Y and 15," G.R. Harbaugh, and D.A. Steinhurst, Nova Technical Report NOVA-2031-TR-0003, October 01, 2007.

"ESTCP Wide Area Assessment Pilot Program Final Report," Environmental Security Technology Certification Program, document in preparation.

"Wide Area UXO Contamination Evaluation by Transect Magnetometer Surveys, Pueblo Precision Bombing and Pattern Gunnery Range #2, Demonstration Data Report," G.R. Harbaugh, D.A. Steinhurst, N. Khadr, Nova Technical Report NOVA-2031-TR-0001, October 3, 2006.

"Conceptual Site Models to Support ESTCP Wide Area Assessment Demonstration Project – Final Version 0, July, 2005," Versar, Inc., July, 2005.

"Wide Area UXO Contamination Evaluation by Transect Magnetometer Surveys, Victorville Precision Bombing Ranges Y and 15, Demonstration Data Report," G.R. Harbaugh, D.A. Steinhurst, N. Khadr, Nova Technical Report NOVA-2031-TR-0002, October 3, 2006.

"Site Inspection (SI) Work Plan, Former Camp Beale, Yuba and Nevada Counties, California, September, 2004, Appendix K, Conceptual Site Model," U.S. Army Corps of Engineers, Sacramento District, Sacramento, CA, September 2004, http://www.campbeale.org/proj_profile/docs_issued/docs/siwp/pdf_d11/siwp_d11_apxK.pdf.

APPENDIX A

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